The Helicopter/Ship Dynamic-Interface Problem

– A New Approach –

By

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ABSTRACT

A wind-tunnel test was conducted in the Boeing Vertol low-speed V/STOL tunnel to assess aerodynamic wake turbulence behind the superstructure of a 1/50-scale FF1052-class U.S. Navy frigate. The principal objective was to measure dynamic velocity data at a sufficient number of locations in the separated wake to define major areas of turbulence affecting helicopter operations aboard ship. The eventual goal of the ship wake program is to apply the results in piloted flight simulation work aimed at solving ship/helicopter dynamic-interface problems.

This paper documents the testing accomplished to map the turbulent wake and presents a sampling of the more interesting results gleaned from the test.

BACKGROUND

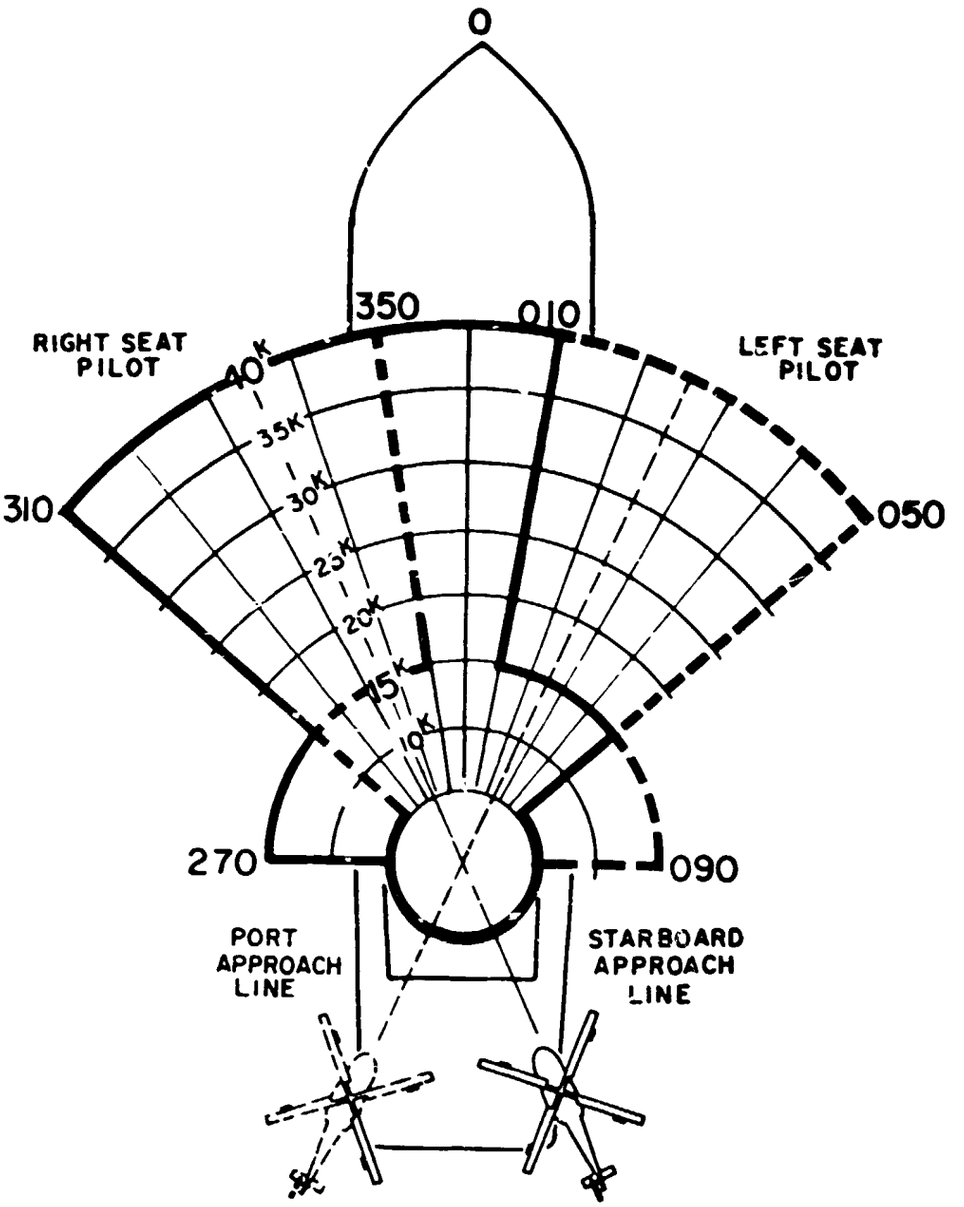
The United States Navy currently operates at least five different helicopter models from over 70 separate classes of nonaviation-type ships, such as destroyers, frigates, etc. Deployment of helicopters from the small helipad-size flight decks on these vessels creates a number of interesting handling qualities and performance problems not generally encountered when the aircraft are operated ashore.

Included among the more difficult of these dynamic-interface problems, as they are typically called, are the ship/aircraft limitations resulting from winds blowing across the deck and hull superstructure. These winds produce both unwanted turbulence in the landing area and crosswind/tailwind conditions affecting aircraft launch and recovery envelopes. When taken collectively with considerations of ship motion (and vessel configurational peculiarities that may exist in the area of the landing pad), the wind limitations define a dynamic-interface operating envelope which is unique for every helicopter/ship combination. A typical SH-2D launch and recovery wind-limitation envelope (Reference 1) for operations off a DE1052-class ship is shown in Figure 1. This is for daytime conditions with minor ship roll oscillations present. Restrictions become more severe with increased ship roll angles and reduced nighttime visibility, and depend on aircraft-system status such as ASE on/off, or on availability of ship landing aids, etc.

Traditionally, all dynamic-interface envelopes have been based on results of testing at sea. When a new helicopter is first flown aboard a nonaviation ship, extensive compatibility flight-testing is conducted with the ship under way to establish approach and departure envelopes for various wind and sea conditions. Because of the high costs of these tests and difficulty in obtaining the proper weather conditions, only a limited number of data points are obtained. Construction of the total diagram requires a large amount of engineering/pilot judgment and unless the critical conditions were flown, are usually conservative. In addition, only the most important testing has been accomplished so far. The largest number of tests, including those associated with new helicopters (such as the LAMPS Mark III vehicle) or ships not yet in service, remain to be done.

SH-2D Launch and Recovery Wind Limitations

DE-1052 CLASS SHIPS



DAY

0-5 DEGREE ROLL

STARBOARD —— SOLID LINE
PORT — — — — DASH LINE

Figure 1.

In early 1974, a multiphase exploratory program to develop and evaluate more cost-effective approaches toward dynamic-interface testing was jointly conceived by the Naval Air Systems Command and Boeing Vertol. The principal thrust of this program was to apply piloted flight simulation techniques as an adjunct to, or replacement for, complicated and expensive sea-trial testing. Potential exists for performing elements of this sea-trial work in a flight simulator, for substantially lower costs.

Over the past several years, state-of-the-art piloted flight simulation has become quite sophisticated, with a high degree of realism possible for solving engineering or flight training problems. Mathematical models of the helicopter, suitable for real-time flight simulation, are available with the necessary static and dynamic validity and system complexity. Flight simulator visual displays using closed-circuit television systems viewing terrain boards with scaled surface features can provide the visual fidelity. Using the terrain-model visual approach, ship motion can be introduced through a servoed ship model mounted on the terrain board. The missing ingredient for this helicopter/ship exploratory flight simulation program was an accurate representation of the aerodynamic wake turbulence existing behind a nonaviation-type ship.

To obtain the necessary data, a wind-tunnel program using a scaled FF1052-class Navy frigate model was conducted in June 1976 in the Boeing Vertol V/STOL wind tunnel. The 8-foot 10-inch-long, 1/50-scale waterline-type wind tunnel model was provided for the test by the Naval Air Systems Command (NASC) and was acquired from the Naval Ship Research and Development Center (NSRDC) in Bethesda, Maryland. The general approach followed in conducting the test and principal results gleaned therefrom are the subject of this paper. Complete test data is presented in Reference 2.

TEST EQUIPMENT AND MODEL

Figure 2 presents a sketch of the ship model as it was installed in the tunnel test section on an elevated 20-by-20-foot-square ground plane. Inserted between the hull and ground plane was an adapter block which ensured that all hull components above the waterline would be out of the ground-plane boundary layer velocity gradient. Alternate adapter blocks permitted the hull to be rolled 30 degrees right and left of vertical.

To simplify testing and positioning of the velocity-measurement equipment, the entire hull could be yawed (about the centerline of its helicopter landing pad) from 0 degrees to 180 degrees in either direction (see Figure 5). All testing was accomplished by rotating the ship to the right only and assuming data symmetry for the opposite yaw direction.

Accurate measurement of wake turbulence was accomplished with a grid of extremely sensitive split-film hot-wire anemometer probes (TSI Model 1080) attached to a movable rectangular rake as shown in Figures 3 and 4. Probe arrangement on the rake was carefully chosen on the basis of predicted location of vortices, and through application of smoke-flow-visualization techniques around the ship superstructure, to define the principal areas of turbulence in the lee of the hull.

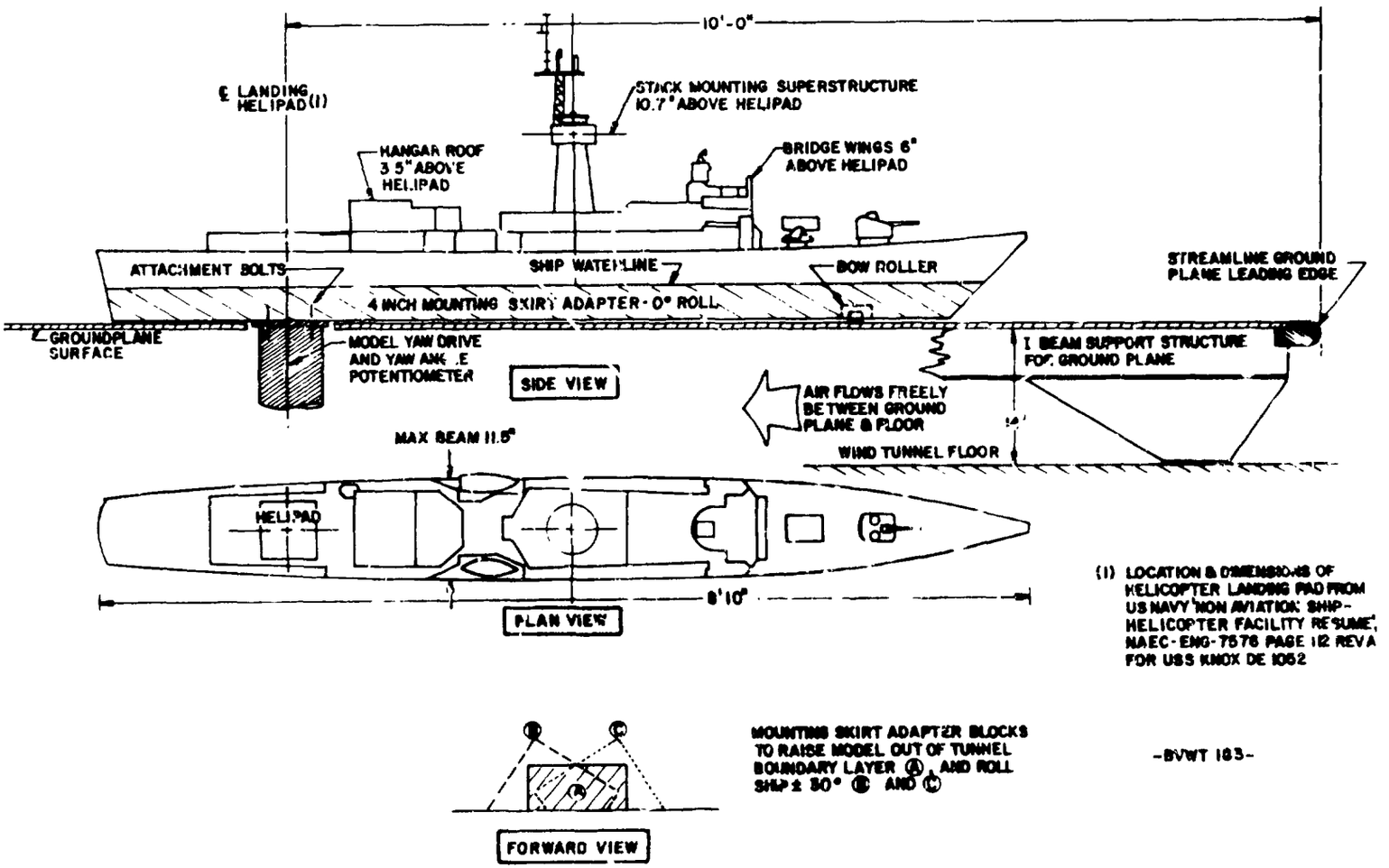
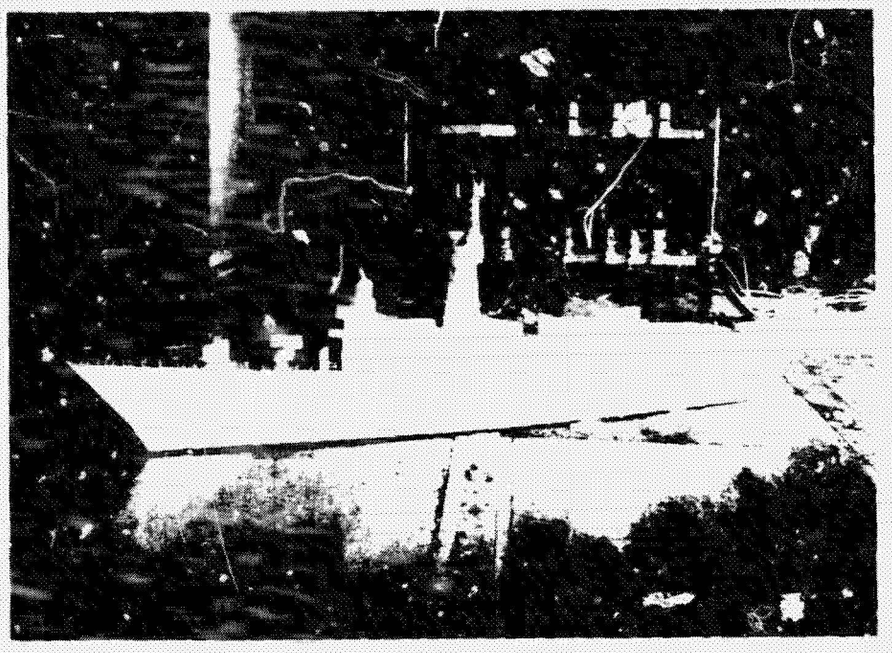
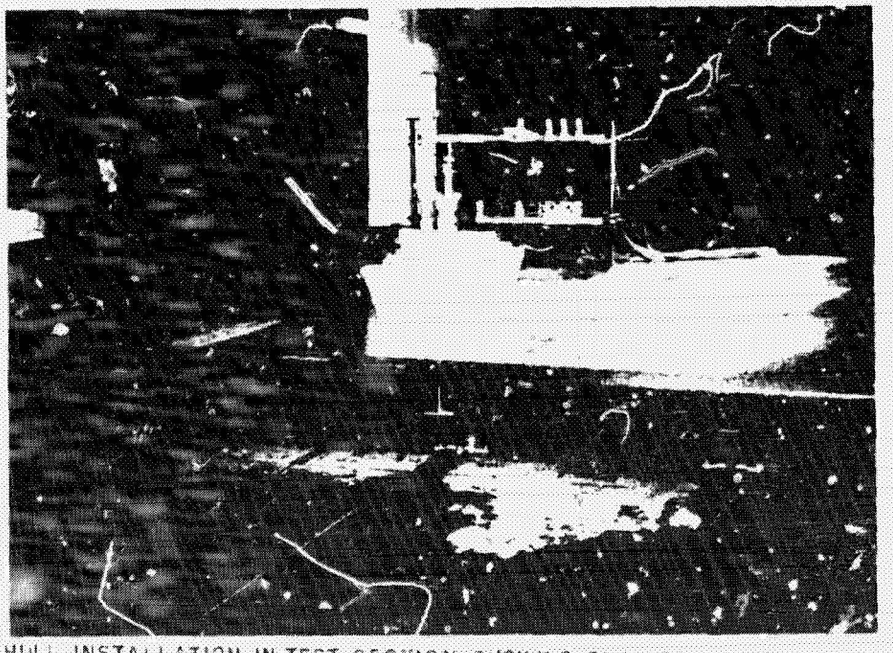

10'-0"
℄ LANDING HELIPAD(1)
STACK MOUNTING SUPERSTRUCTURE 10.7" ABOVE HELIPAD
HANGAR ROOF 3.5" ABOVE HELIPAD
BRIDGE WINGS 6" ABOVE HELIPAD
ATTACHMENT BOLTS
SHIP WATERLINE
BOW ROLLER
STREAMLINE GROUND PLANE LEADING EDGE
4 INCH MOUNTING SKIRT ADAPTER - 0° ROLL
℄ GROUNDPLANE SURFACE
MODEL YAW DRIVE AND YAW ANGLE POTENTIOMETER
SIDE VIEW
I BEAM SUPPORT STRUCTURE FOR GROUND PLANE
AIR FLOWS FREELY BETWEEN GROUND PLANE & FLOOR
WIND TUNNEL FLOOR
MAX BEAM 11.5"
HELIPAD
8'10"
PLAN VIEW
(1) LOCATION & DIMENSIONS OF HELICOPTER LANDING PAD FROM US NAVY 'NON AVIATION SHIP-HELICOPTER FACILITY RESUME', NAEC-ENG-7576 PAGE 12 REVA FOR USS KNOX DE 1052
MOUNTING SKIRT ADAPTER BLOCKS TO RAISE MODEL OUT OF TUNNEL BOUNDARY LAYER (A) AND ROLL SHIP ± 30° (B) AND (C)
-BVWT 183-
FORWARD VIEW

Figure 2. Wind Tunnel Ship Model Geometry – 1/50 Scale DE 1052 (FF1052) Showing Installation in Tunnel Test Section



DE 1052 HULL MOUNTED ON 0° ROLL ANGLE ADAPTER SKIRT WITH "LOWER INBOARD" PROBE ARRAY (UNITS 1 THRU 7) ACTIVE



HULL INSTALLATION IN TEST SECTION SHOWING GROUND PLANE MOUNTING DETAILS

Figure 3. Ship Aerodynamic Wake Turbulence Test — DTNSRDC 183

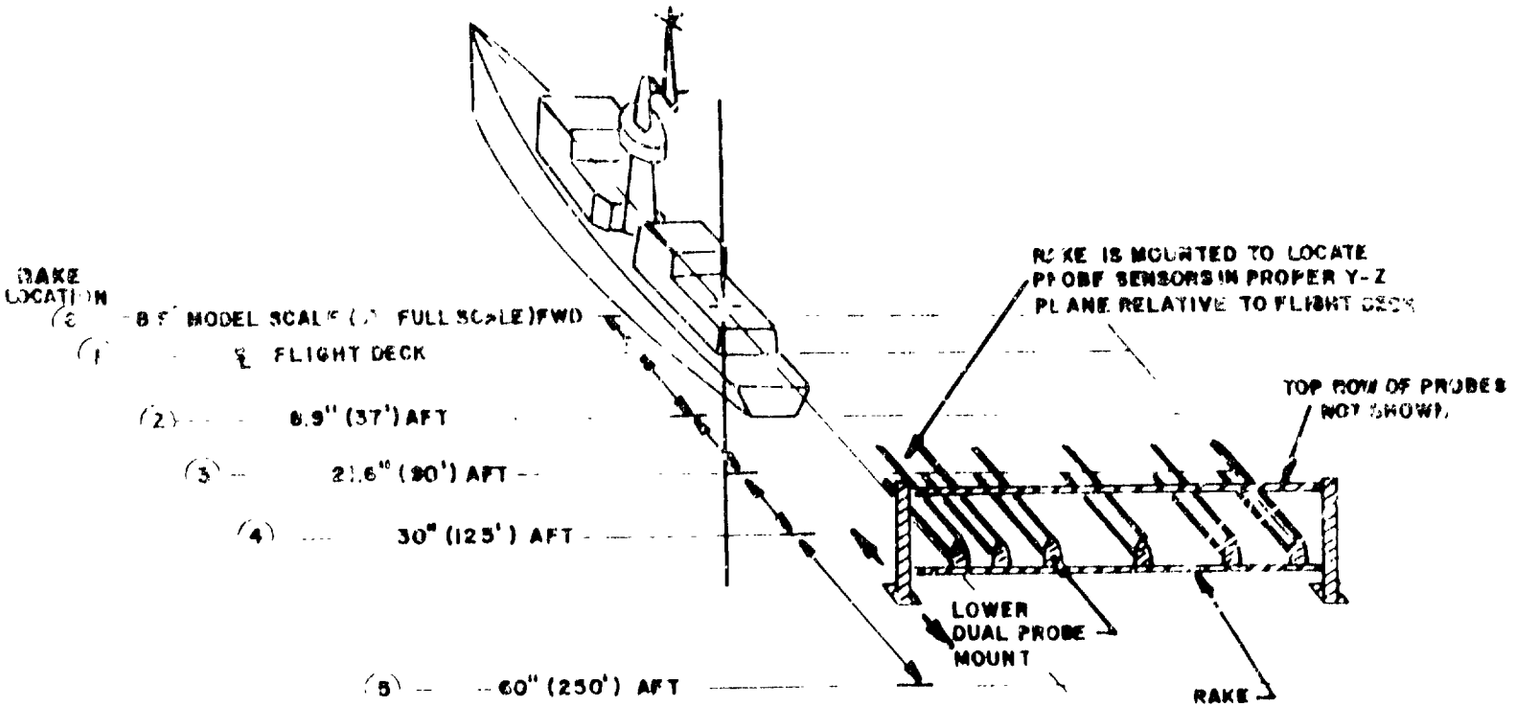

RAKE LOCATION
(5) 8.5' MODEL SCALE (FULL SCALE) FWD
(1) ℄ FLIGHT DECK
(2) 8.9" (37') AFT
(3) 21.6" (90') AFT
(4) 30" (125') AFT
(5) 60" (250') AFT
RAKE IS MOUNTED TO LOCATE PROBE SENSORS IN PROPER Y-Z PLANE RELATIVE TO FLIGHT DECK
TOP ROW OF PROBES NOT SHOWN
LOWER DUAL PROBE MOUNT
RAKE

Figure 4. Anemometer Rake Positioning

TEST PROCEDURE

As shown in Figures 4 and 5, the anemometer rake was normally installed behind the ship and oriented perpendicular to the remote tunnel flow, with the probes parallel to the tunnel centerline. Initial tests were conducted with probe sensors located in a vertical plane passing through the landing-pad centerline and in horizontal planes intersecting the top of the hangar roof and forward-bridge superstructure. The ship was yawed in 10- to 20-degree increments to the right as far as was practical (without having the sensors hit ship superstructure).

Yaw sweeps were first accomplished at 20 knots tunnel velocity, followed by runs of 35 and 45 knots. After finishing the high-speed sweep, the rake was moved 8.9 inches rearward to position probe sensors in a plane parallel to the end of the landing-pad deck. The process was repeated by moving the rake further aft to the ship's fantail, and then in steps as shown in Figure 4 to a location 60 inches (or 250 feet full scale) behind the landing pad. With the hangar-roof and bridge-plane turbulence measured, the probes were then moved up vertically to check vorticity shed by the mast and its gas-stack mounting structure. Yaw runs similar to those just described were made with this probe configuration.

In addition to testing performed with the probes mounted horizontally, 24 runs were accomplished at the end of the program to evaluate tailwind airflow over the landing-deck area. Probe orientation for these runs was vertical, and the hull yaw angles were varied between 120 degrees and 180 degrees.

All runs with the ship mounted at zero roll angle (except for those with probes in the gas-stack/mast plane) were repeated with the hull rolled 30 degrees right and left. A total of 137 data runs, with 7 to 8 yaw angles each, were accomplished during the program, for a grand total of over 950 test points taken.

In addition to the velocity-measurement runs, color movies of the turbulent-flow areas behind the ship were made with the hull mounted at all three roll angles. Vorticity patterns downwind of the hull were delineated by smoke released in front of various superstructure elements, or by helium-filled soap bubbles illuminated with a bright light.

DATA RECORDING AND PROCESSING

Each hot-wire anemometer probe produces electronic signals from its three orthogonally oriented split-film sensors which vary with wind velocity and direction. Velocity information from the anemometer probes was recorded and processed on the wind-tunnel IBM 1800 computing system. Raw probe-sensor data was stored initially on tape and then converted to engineering units, using calibration constants derived for each probe. Velocity information was resolved into Vx, Vy, and Vz components so that Vx was always (+) in the downstream direction parallel with the tunnel centerline; Vy (+) to the left looking forward; and Vz (+) upward and perpendicular to the ground plane. This velocity convention was maintained regardless of ship heading, in order to simplify later application of the data in flight simulation work.

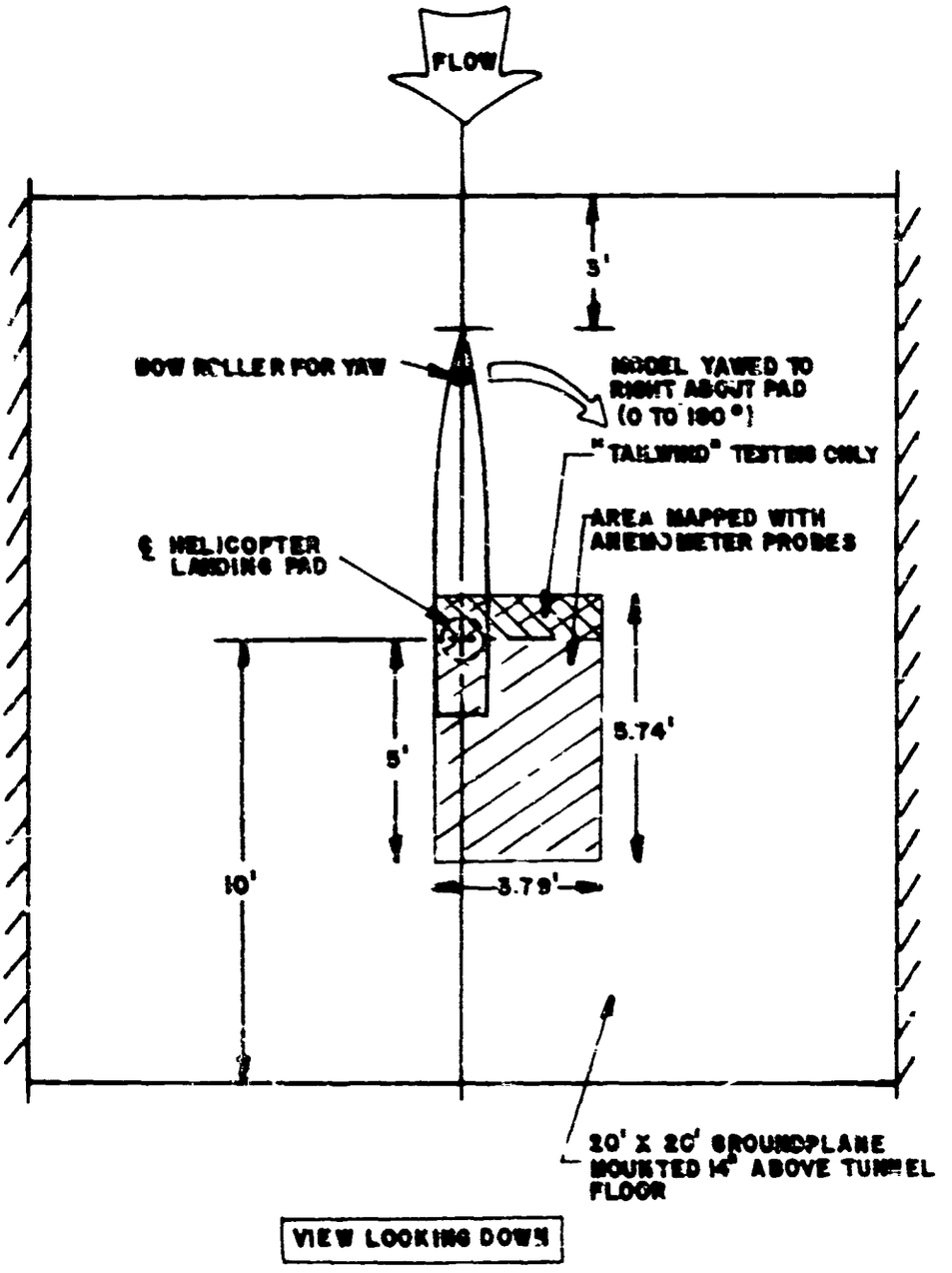


Figure 5. Ship Model Installation in Wind Tunnel

Dynamic-velocity data was recorded after first setting up the desired hull yaw angle, and then stabilizing tunnel speed on the nominal value. 1.6 seconds of data were simultaneously recorded for all probes, followed by a shorter 0.75-second run for quick-look on-line checks of the test results. The 1.6-second model-data burst is equivalent to 80 seconds of full-scale wake turbulence, according to Strouhal scaling-law similarities for the 1/50th-scale ship.

During the 1.6-second run, 262 data samples were recorded, which is one every 0.006 second. This sample rate was primarily dictated by constraints of the data system, as influenced by the number of probe-sensor signals being multiplexed and the desired range of frequency content in the final results. Assuming a minimum of four samples per cycle to define waveform, the data sample rate and run time used in the wake-turbulence test permitted accurate measurement of frequencies between 0.625 Hz and 50 Hz, model scale.

To refer these frequencies to full-scale values, Strouhal number was assumed to be the same for the model and full-size ship (since the minimum Reynolds Number experienced in the model test exceeded 10^3, which is the criterion for constancy established in Reference 3). Strouhal frequency-scaling laws state that:

$$S = \frac{fh}{V}$$

where: S is Strouhal number (usually constant for a given body shape)
f is the frequency of the shed vorticity
h is a characteristic dimension of the body (normally width)
V is the flow velocity.

Based on these relationships, the full-scale range of frequencies possible from the test results can be derived from model-frequency data by simply dividing by the scale factor (50:1). This division results in full-scale turbulence frequencies ranging from 0.0125 Hz to 1.0 Hz, which is more than adequate for application in existing helicopter simulation math models. Scaling the recorded model time history data for simulation work requires only that the 0.006-second time between data samples be increased to 0.3 second.

TEST RESULTS

The principal results of the wake-turbulence wind-tunnel test include a series of velocity time-histories recorded (in engineering units) on magnetic tape for every run, test point, and probe. Also included in Reference 2 is a computer-printout listing of the same information processed to derive steady-state mean and standard-deviation velocity components for all runs. No attempt has been made to analyze the test results in any comprehensive depth at the present time for this paper. Rather, the data have been reviewed for validity and samples of the more interesting results are included.

A typical time-history representing the longitudinal Vx velocity component for a single probe located 125 feet (full scale) directly behind the left corner of the hangar roof is shown in the computer-drawn plot illustrated in Figure 6. In addition to the time-history trace,

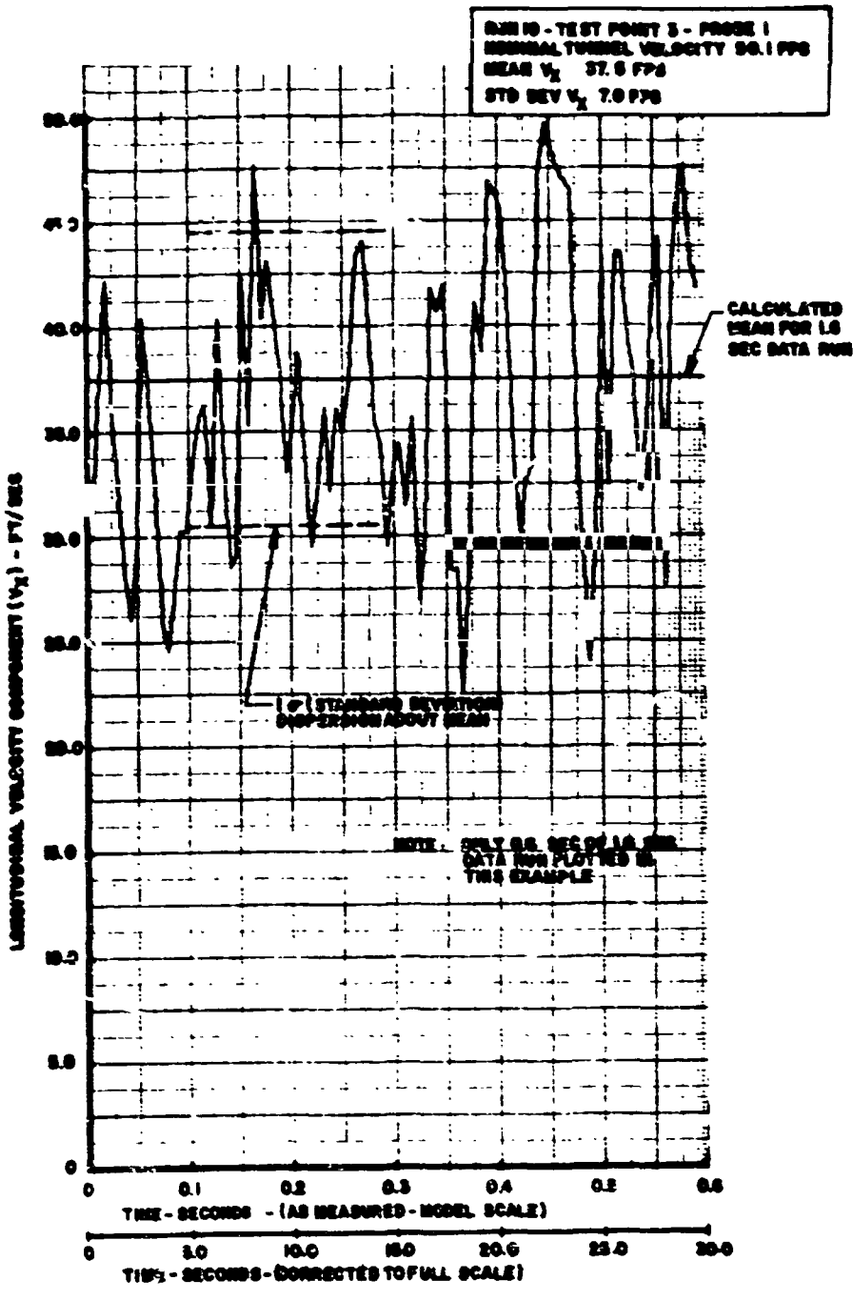


Figure 6. Typical Velocity Time History

the calculated mean and standard-deviation values are shown for the particular test point. It is interesting to note that the mean velocity for the run is less than 2/3 of the 35-knot free-stream flow, because of turbulent separation existing at the probe location. The standard deviation about this mean is approximately 20 percent of the average steady-state velocity level, indicating roughness in the flow. This roughness was observed to grow significantly as the ship yaw angle was increased relative to the remote wind.

Figure 7 presents the steady flow field in the plane of the hangar roof (14.6 feet above the deck), with the ship yawed 30 degrees to the 20-knot remote wind. The data was constructed from a vector summation of the Vx and Vy mean-velocity data. It clearly indicates a skewing of the flow, as it becomes more aligned to the ship's fore/aft axis, and a significant velocity reduction behind major elements of the ship superstructure.

The principal effects of increasing yaw angle to 50 degrees are shown in Figure 8. Typical velocities on the order of 1/3 or less of free steam are apparent behind the hull and their directional orientation indicates large areas of swirling or eddying in the wake. Despite these characteristics, the steady flow field is amazingly stable in magnitude and direction, as indicated by the repeated test points.

When compared with Figure 7, Figure 9 illustrates a marked change in flow pattern over the landing-pad area. In Figure 9, the probes are in the plane of the forward bridge, 11.4 feet higher than those of Figure 7. For both cases, the ship is at 30 degrees yaw. Flow direction has changed by 30 to 40 degrees over the fantail area in a clockwise direction through this 11.4-foot altitude reduction.

Steady-state flow patterns in vertically oriented planes have been obtained through a vectorial sum of Vx and Vz. Figure 10 presents the data taken in the plane of the hangar roof, again with the ship yawed 30 degrees in 20-knot wind. The figure illustrates orientation of the flow in vertical planes aligned parallel to one another as shown in the sketch at the bottom right side of the figure. The plot is viewed from the left, as if the reader were looking at a series of six vertical planes, with data from one probe only shown in each plane, and with the probe positioned at rake locations 1 through 6 as indicated by the sketch. Upward flow is directed to the right on the chart. The significant test results apparent in this figure are the large changes in vertical-flow velocity existing with only 20-knot winds blowing across the ship. These translate into aircraft climb or descent requirements in order to maintain level flight near the vessel. Comparing probe 7 at rake location 1 and probe 9 at rake location 2 (which are approximately 1 rotor diameter apart, when considering LAMPS-size aricraft), a net change in vertical velocity exceeding 1,000 feet per minute is experienced. This flow change would be equivalent to introducing a gust-ramp of over 16 feet per second into the helicopter rotor system, if the aircraft were flown behind the hull with the rotor at hangar-top height. Some other approach path to the ship which avoids this area is desirable.

Data taken at 35 and 45 knots shows flow directions virtually identical to those at 20 knots, indicating that, at least for mean velocity, only one set of data is required with remote wind scaling.

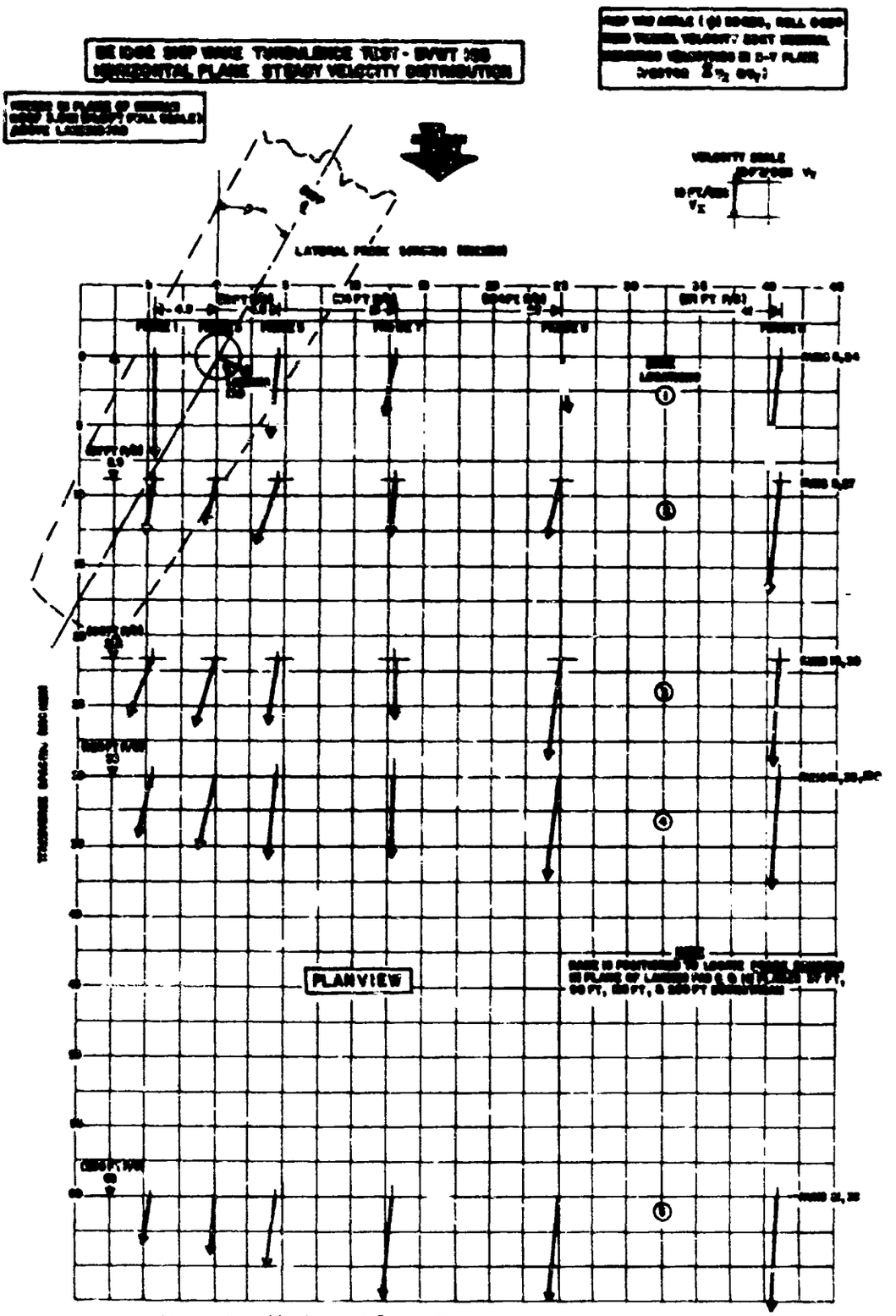


Figure 7. Horizontal Plane Steady Velocity Distribution

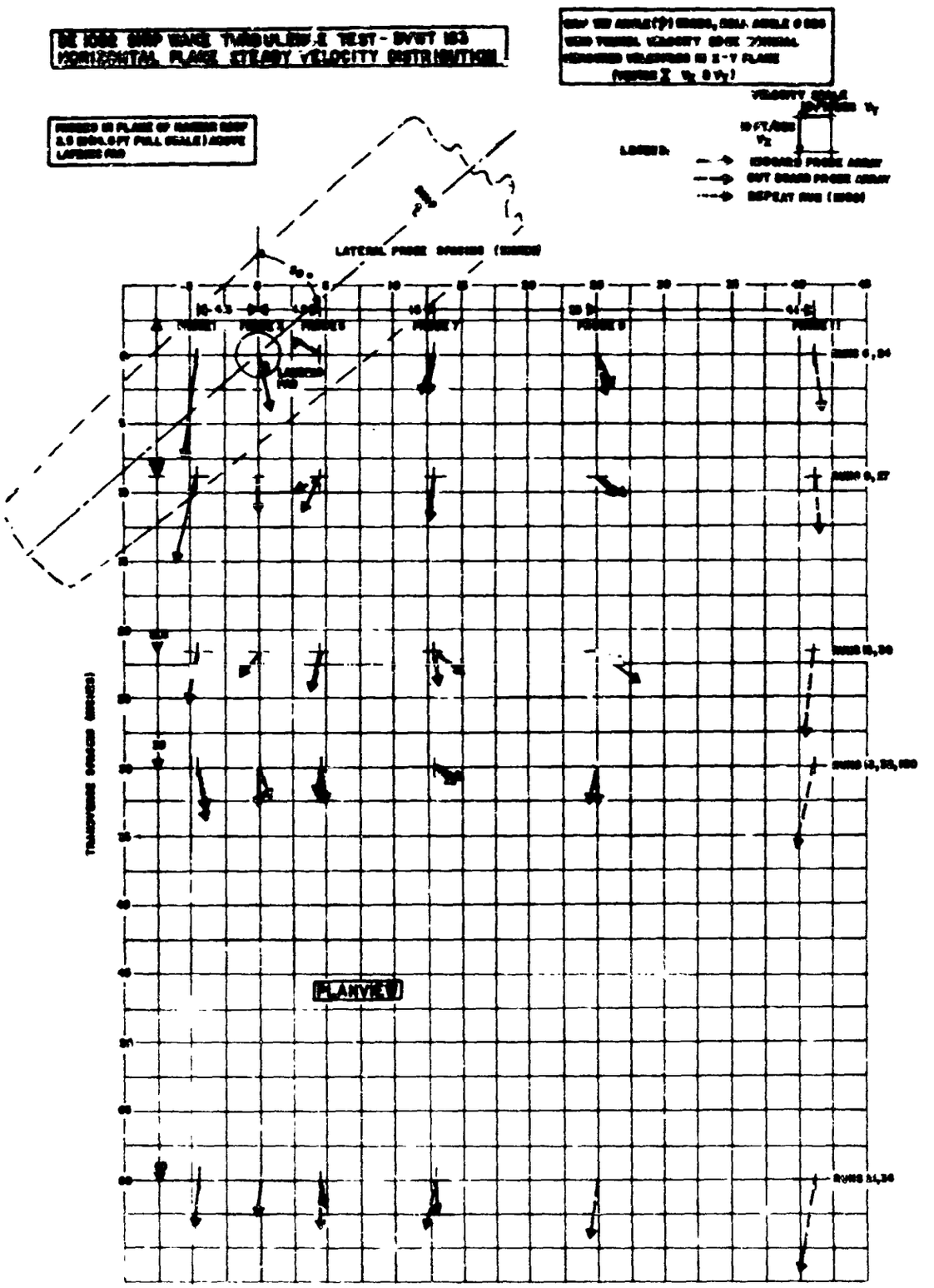


Figure 8. Horizontal Plane Steady Velocity Distribution at 50 Degrees Ship Yaw Angle and 20 Knots Wind Tunnel Velocity at Hanger Top Height

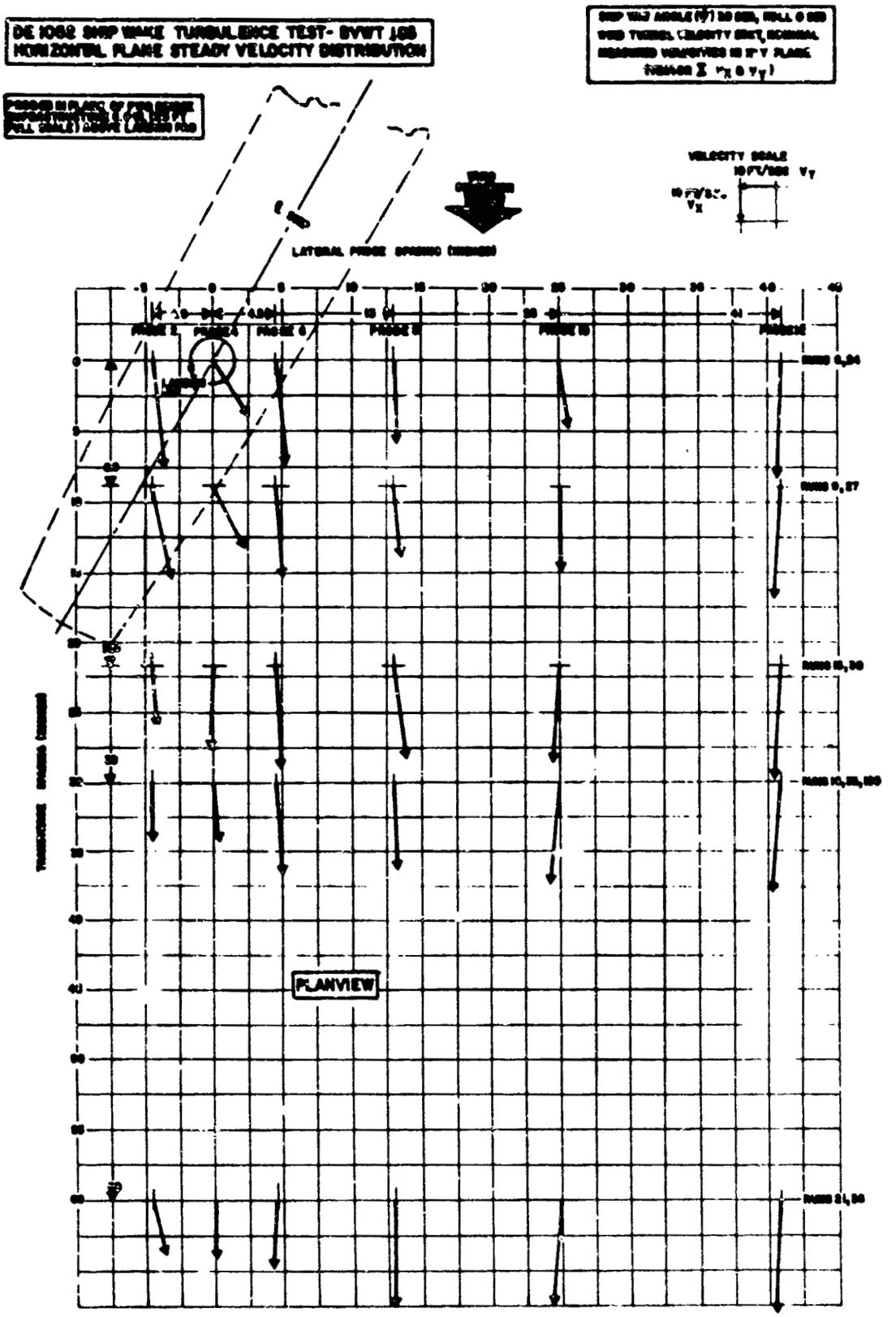


Figure 9. Horizontal Plane Steady Velocity Distribution at 30 Degrees Ship Yaw Angle and 20 Knots Wind Tunnel Velocity at Bridge Height

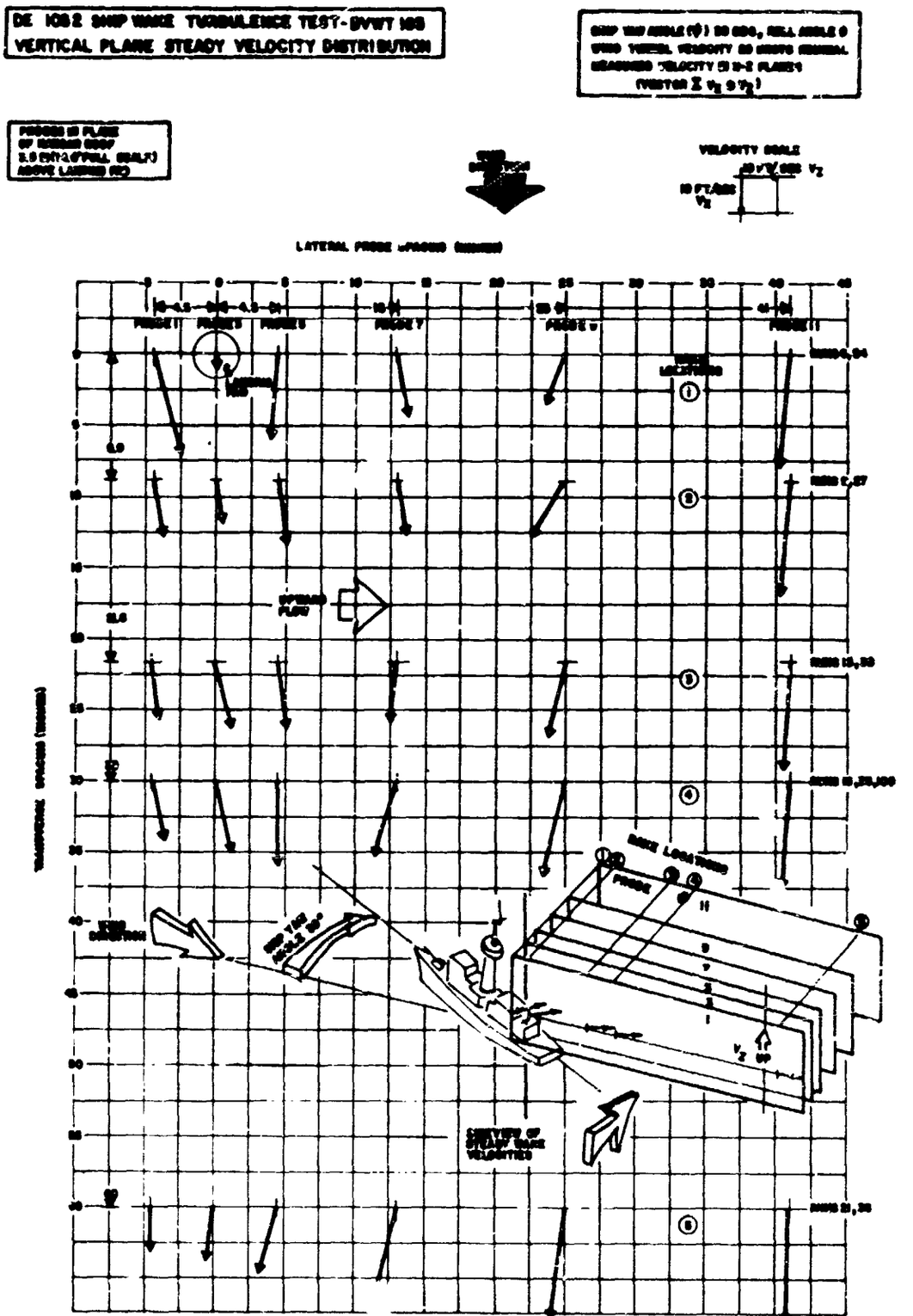


Figure 10. Vertical Plane Steak Velocity Distribution at 30 Degrees Ship Yaw Angle and 20 Knots Wind Tunnel Velocity at Hangar Top Height

The frequency content of the turbulence was observed on-line during the program to assure adequacy of the sampling rate. A sample of data for Vx is shown in Figure 11 for the noted conditions. Low-frequency-velocity amplitudes are high, approaching 5 feet per second, which is close to 10 percent of the remote velocity and 35 percent of the mean at this location. Most of the significant turbulent energy is below 20 Hz model scale or 0.4 Hz full scale.

DATA APPROACHES FOR FLIGHT SIMULATION

At the present time, two approaches toward using the wind tunnel turbulence data for future flight simulation work appear viable. The first involves application of the steady-state (mean) velocity information in concert with some type of computed random-turbulence function. The second (and somewhat more cumbersome) approach would be to store the Strouhal-scaled, time-history, dynamic-velocity data points directly in the computer, after first performing a time correlation of information from the various probes. Selection of the required data application methodology depends upon the results of further data analysis, including turbulence power-spectra calculations for each data point. If the spectra are similar, the first approach would be superior.

ADDITIONAL APPLICATION OF TEST RESULTS

Start-Up/Shut-Down Limitations

The turbulence data can also be used in conjunction with rotor-blade flapping analyses to estimate wind limitations during rotor start-up and shut-down.

V/STOL/RPV

Approaches similar to those being developed for helicopter launch and recovery envelopes can be used for all types of V/STOL aircraft and remotely piloted vehicles.

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2. Garnett, Theodore S., Jr., INVESTIGATION TO STUDY THE AERODYNAMIC SHIP WAKE TURBULENCE GENERATED BY AN FF1052 FRIGATE, Contract No. N00019-75C-0493, Naval Air Systems Command, Washington, DC, AIR-530112, December 1976.

3. Hoerner, S.F., FLUID DYNAMIC DRAG, published by the author, 1958.

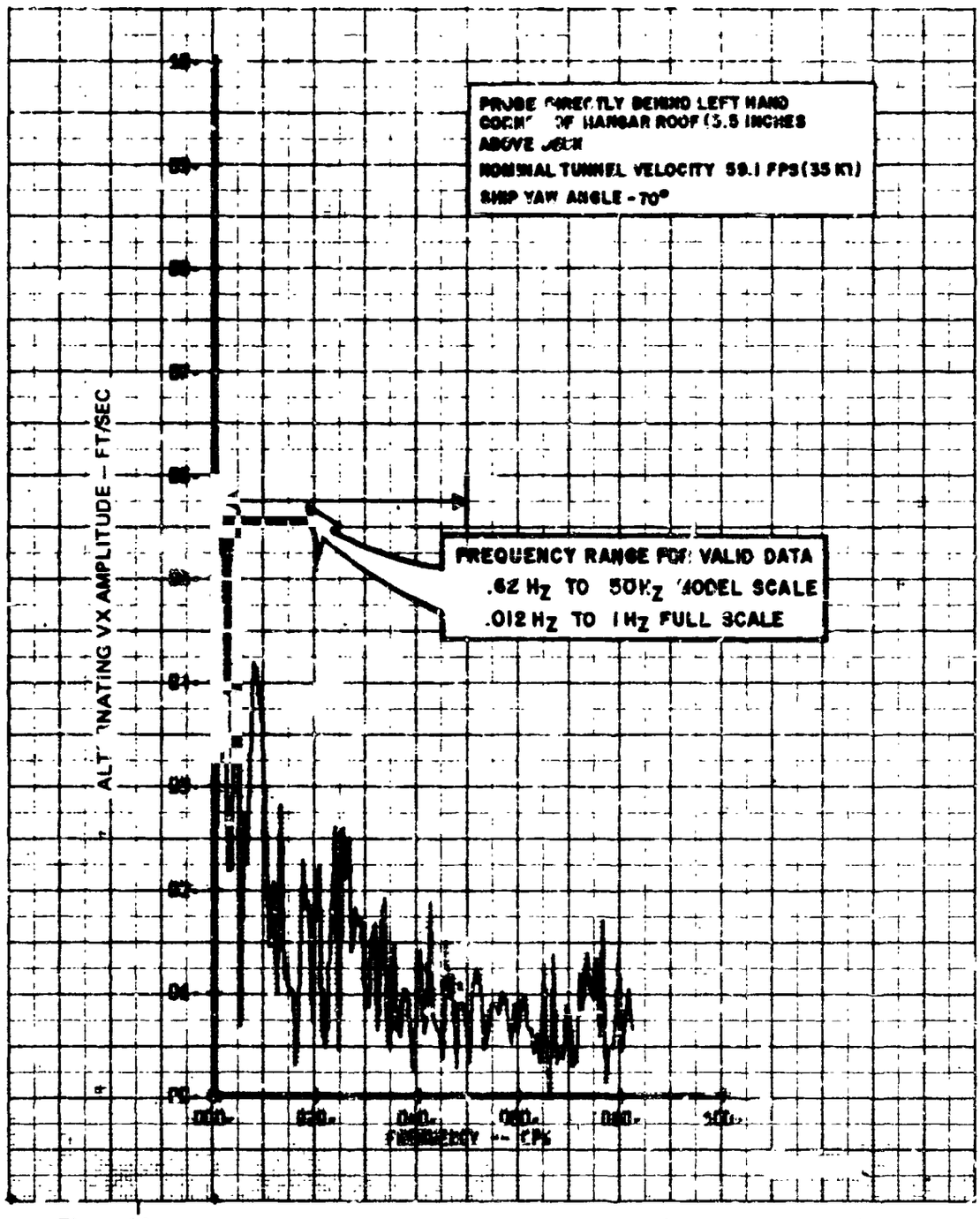
PROBE DIRECTLY BEHIND LEFT HAND
CORNER OF HANGAR ROOF (3.5 INCHES
ABOVE DECK
NOMINAL TUNNEL VELOCITY 59.1 FPS(35 KT)
SHIP YAW ANGLE - 70°
FREQUENCY RANGE FOR VALID DATA
.62 Hz TO 50 Hz MODEL SCALE
.012 Hz TO 1 Hz FULL SCALE
ALTERNATING VX AMPLITUDE -- FT/SEC
FREQUENCY -- CPS

Figure 11. Ship Wake Velocity Survey, Vx Vs. Frequency, Probe Behind Left Corner of Hangar Roof, Run 19 TP 5

LtCOL Iles: Am I to understand that you're planning to come up with dynamic interface limitations for ships and helicopters? Right?

Garnett: The limitations right now are specified for the aircraft. All we really want to do is to obtain information to assist in setting the scope of testing that's to be done at sea. Obviously you have to do the final test at sea. We just want to cut down the amount of data points that are required. If we are able to cut the task time at sea by half, the program would have more than paid for itself.